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Atmospheric Measurement Techniques Discussions

Interactive comment on "Limb–nadir matching using non-coincident NO_2 observations: Proof of concept and the OMI-minus-OSIRIS prototype product" *by* Cristen Adams et al.

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We thank you for your comments, which have helped to improve our manuscript. Below we address the recommended changes point-by-point.

– One advantage of the proposed method with respect to the commonly used CTM approaches is that it does not suffer from errors introduced by the CTM's (usually) coarse spatial resolution, leading to photochemical representation errors close to the terminator. While this is not of concrete importance to the present study due to its SZA filter criteria, it would be nice if the authors could add a sentence about this fact.

We have added the following text to Sect. 3.1

"One advantage to this approach is that the photochemical box model provides high temporal resolution at twilight, when NO2 is changing rapidly. Chemical transport models often have coarse spatial resolution (e.g., 1-3°), which can lead to errors in photochemical representation close to the terminator. For this study, these errors are unlikely to be a major factor as OSIRIS measurements are for SZA < 88° and OMI measurements are for SZA < 75°. Another advantage is that we are able to, on a profile-by-profile basis, constrain the diurnal cycle with accurate and simultaneously measured ozone profiles as well as measurement-based representations of other input parameters."

– The authors should acknowledge the possibility to use both OSIRIS measurements from one day to better constrain the diurnal cycle from the box model. In principle, in those cases when two OSIRIS measurements (morning + evening) per day are available, this could further improve the retrieval method.

This is a good idea, and one we have thought about previously. However, for most of the OSIRIS mission it would only be possible for small and annually-varying subsets of latitudes. For the year we have chosen to use in this study, 2008, the LSTs of OSIRIS are roughly 7am and 7pm. This provides the maximum morning coverage as it corresponds to the latest OSIRIS measured in the morning, but also a minimum on the evening side of the orbit. As mentioned in section 2.2 (the last paragraph), maximizing coverage for one half of the orbit is the main reason why 2008 was chosen.

– p.3/l.28-29: the authors write of SCIAMACHY limb and nadir instruments. However, the nice thing about SCIAMACHY is that it's the same instrument. Maybe better write measurement modes or viewing geometries

We have changed "limb and nadir instruments" to "limb and nadir viewing geometries" in the text. We have also specified that limb and nadir measurements are from the same instrument earlier in the paragraph.

– p.6/l.10: In the discussion of AMFs, the authors should also write that the AMF

depends on the solar and viewing azimuth angles (due to the asymmetry of aerosol phase functions).

We have added “solar azimuth angle” to the list of parameters that the AMF depends on. We have not added the “viewing azimuth angle” because the list already included “satellite viewing angle”. This now reads “The AMF is dependent on the path length, which in turn depends on the solar zenith angle (SZA), solar azimuth angle, the satellite viewing angle, the vertical distribution of absorbing species, cloud and aerosol properties, and albedo.”

– p.6/l.16: Surface reflection is not calculated by the radiative transfer models, but it is rather an input to RTMs.

We have changed “surface reflection” to “reflection off the surface” to clarify that this refers to the modelled path of the sunlight and not an input albedo variable.

– p.6/l.17: Maybe the authors want to say SCDs instead od VCDs?

AMFs and VCDs are provided in the OMI data files. SCDs were calculated from these as part of our analysis procedure. This has been clarified by changing the word “dataset” to “data files” and adding a reference to the OmO calculation equations, as follows:

“The OmO prototype dataset was constructed using the AMFs and VCDs from the OMI-SP v2 data files (Bucsela et al., 2013), using the methodology given in Sect. 4.3.”

– p.6/l.22: The authors should shortly explain why they limit themselves to SZA<75 What goes wrong at larger SZAs? What are the implications of this limitation for the applicability to geostationary measurements of high latitude (especially relevant for Sentinel-4/UVN over Europe in winter)?

The radiative transfer models used to calculate the air mass factors are based on plane-parallel geometry and therefore once a SZA of 75-80° is reached, systematic errors will be introduced. Many spherical models exist, however, and so this is more of a soft

limitation. A second point is that as the path length of the incoming sunlight increases, more light is scattered out higher up in the atmosphere, and the effect of this is to reduce the sensitivity to the near-surface layers. While a detailed description of how this will impact geostationary sensors is beyond the scope of our present study, we can say that territories north of 55-60°N will have days-to-weeks when no measurements can be made.

– p.9/l.1: Maybe the word extrapolated would fit better than scaled?

“Scaled” has been replaced with “extrapolated”

– p.9/l.27-29: What is the time-step of the box model, what is the spacing of the t_new grid?

We have added the following text to address this:

“The box model time-steps are calculated from the sine of the SZA, for a total of 49 time-steps per day. Therefore, toward twilight, when NO2 varies rapidly, there is better temporal resolution than toward noon. The t_new grid is at an hourly resolution, as discussed in Sect. 3.3.”

– p.9/l.30: Don’t all rho also depend on the latitude and day-of-year? Please adjust the Eq. 1 accordingly, to make it more clear to the reader.

Yes, they do. Eq. 1 has been updated to include latitude and day-of-year.

– p.10/l.12: All researchers working on the upper atmosphere would certainly appreciate if the authors could acknowledge that 46km is "effectively the top of atmosphere" only in this context”.

We have added “in this context”, as recommended.

– p.11: The authors talk about "valid" (l.2) and "available" (l.4) NO2 measurements; maybe it would be more instructive for the reader if they would instead explicitly write above-tropopause, or at least that the TPH determines what a valid or available NO2

data is.

“Valid” and “available” in this context refers to altitude layers with OSIRIS NO2 measurements. These are not determined by the tropopause height, but instead by the quality of the retrieval at each altitude layer. In order to make this more clear in the text, we have replaced the word “valid” with “available” and we explicitly stated “Some OSIRIS profiles terminate above the tropopause and, therefore, information from the photochemical model was used to calculate the full stratospheric VCD . . ..”

– p.12/l.5: OMI measures also at SZA>80; but the authors in this study only use the OMI measurements for SZA<80. This should be clarified.

We have changed “OMI measures for SZA < 80” to “for this study, OMI measurements are used for SZA < 75°”

– p.12/l.13-18: A formula/equation would help to understand the spatial filtering . . .

An equation (Eq. 5) has been added to the description of the filtering method, as recommended in Sect. 3.3.

– p.13/l.3-6: It would be nice if the authors would compare these numbers to other studies of the diurnal variation of strat. NO2, e.g., the Dirksen et al. paper.

We have included a reference to the results of the Dirksen et al. paper, as follows:

“These differences with local time are typically ∼0.4-0.5e15 molecules/cm2, and can locally reach values of up to ∼1e15 molecules/cm2. This is consistent with the daytime rates of increase in stratospheric of NO2 VCDs measured by Dirksen et al. (2011), using OMI and Système d’Analyse par Observations Zénithal (SAOZ) data. They found increase rates that ranged from approximately 0–4e15 molecules/cm2/hour, depending on the latitude and time of year, which would correspond to net increases of 0-2.4e15 molecules/cm2 for the 6-hour local time difference in Figure 4.”

– p.14/l.19: OSIRIS strat. NO2 VCDs could in principle also be matched to not-bias-

corrected OMI SCDs (the resulting VCDs would be wrong, but this is not the point here), so the beginning of the sentence "In order to match" is not correct.

This sentence was replaced with:

“In order to remove systematic mismatches between the OSIRIS stratospheric VCDs and the OMI measurements, the OMI total SCDs were corrected for their high bias.”

– p.14/l.24: Sect. 3.3 does not describe any OMI SCD bias correction?!

This is been corrected to “Sect. 4.3”

– p.16/l.6-7: This sentence seems to be grammatically not correct ("of the individual the gamma-scaled...")

This has been corrected to “of the individual gamma-scaled. . .”.

– p.16/l.14: I personally do see "enhanced [VCDs] across the northern hemisphere Pacific and Mexico" in the OSIRIS data (orange values over Mexico and just west of the measurement gaps over the Pacific).

We agree that these enhancements are faintly visible in the OSIRIS maps. Therefore we have changed the wording from “not apparent in the OSIRIS data” to “not as strong in the OSIRIS data”.

– p.21/l.13-14: TROPOMI (on board Sentinel-5 Precursor) is not a geostationary instrument! The authors are probably referring to the UVN instrument on board Sentinel-4.

This has been corrected to: “three instruments, each on-board a geostationary satellite: . . . TROMPOMI, . . . TEMPO,. . . and GEMS”.

– In all Figures the authors should refrain from using the abbreviation of "mol/cm2", as "mol" is the unit symbol for the S.I. unit for amount of substance, mole.

mol/cm2 has been changed to molec/cm2 in all figures

– In Fig. 6, the caption should explain which statistic (mean, median, . . .) the symbols

denote, and the applied filter criteria should also be mentioned in the caption.

We have changed the figure caption to better describe the figure contents as follows:

"Mean percent difference of OSIRIS minus OMI-SP stratospheric VCDs (x-axis), binned according to latitude (y-axis) and month (legend). OSIRIS VCDs were interpolated from the OSIRIS gridded VCD maps (see Sect. 3.3) to the OMI measurement date, location, and local time. Filtering criteria for the OMI and OSIRIS profiles are given in Sect. 2.1 and 2.2, respectively."

– In Fig. 9, the caption doesn't match the individual subplots' headings (mix-up of DOMINO and SP).

The order of the figure panels has been changed to match the figure label.

– In Fig. A1, the caption should say which year these data are taken from.

This has been specified in the caption.

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